# Electricity from Renewables: An NREL Perspective

## Presented to the National Research Council

## December 6, 2007

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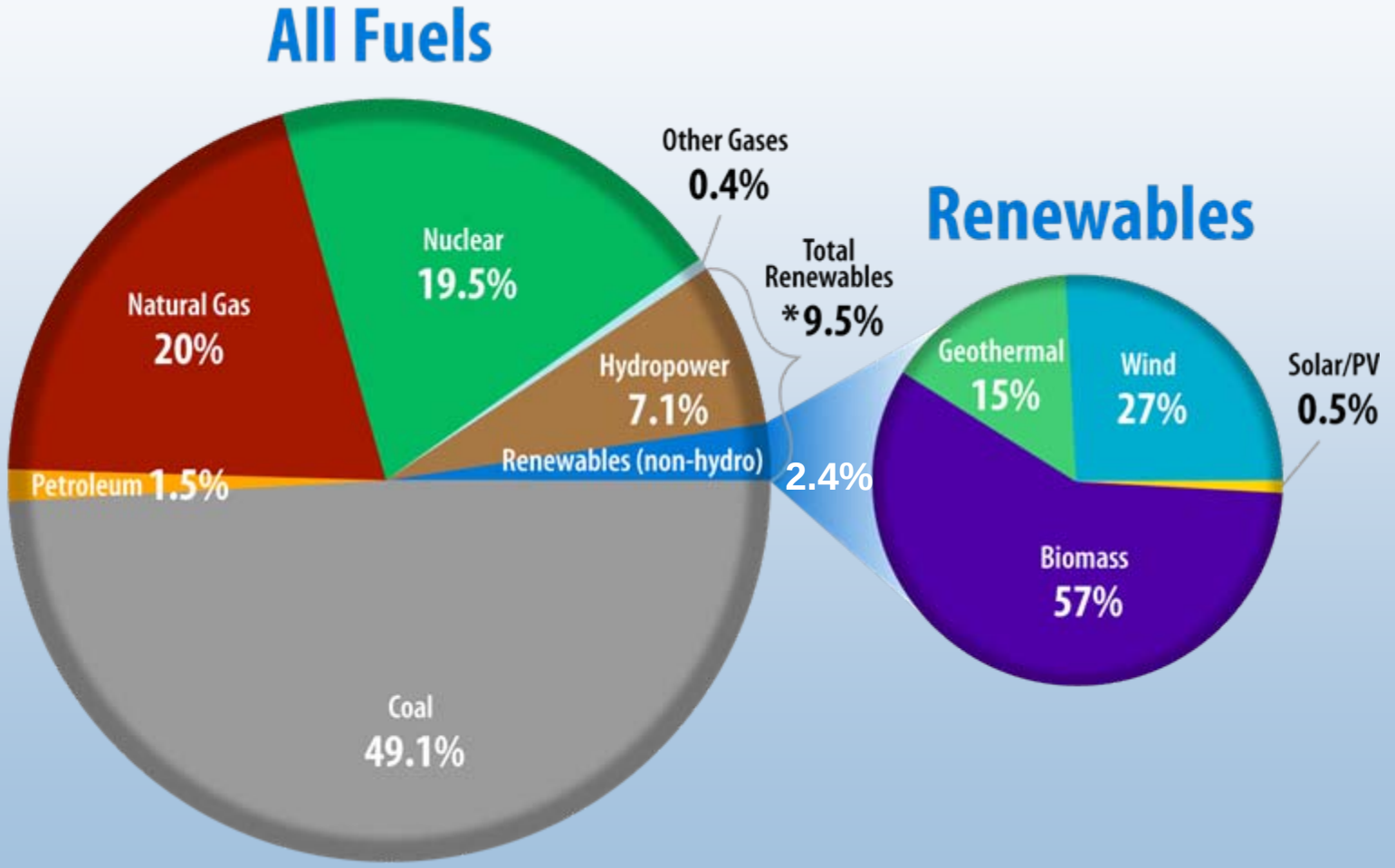
Director, National Renewable Energy Laboratory

# What Are the Major Renewables?

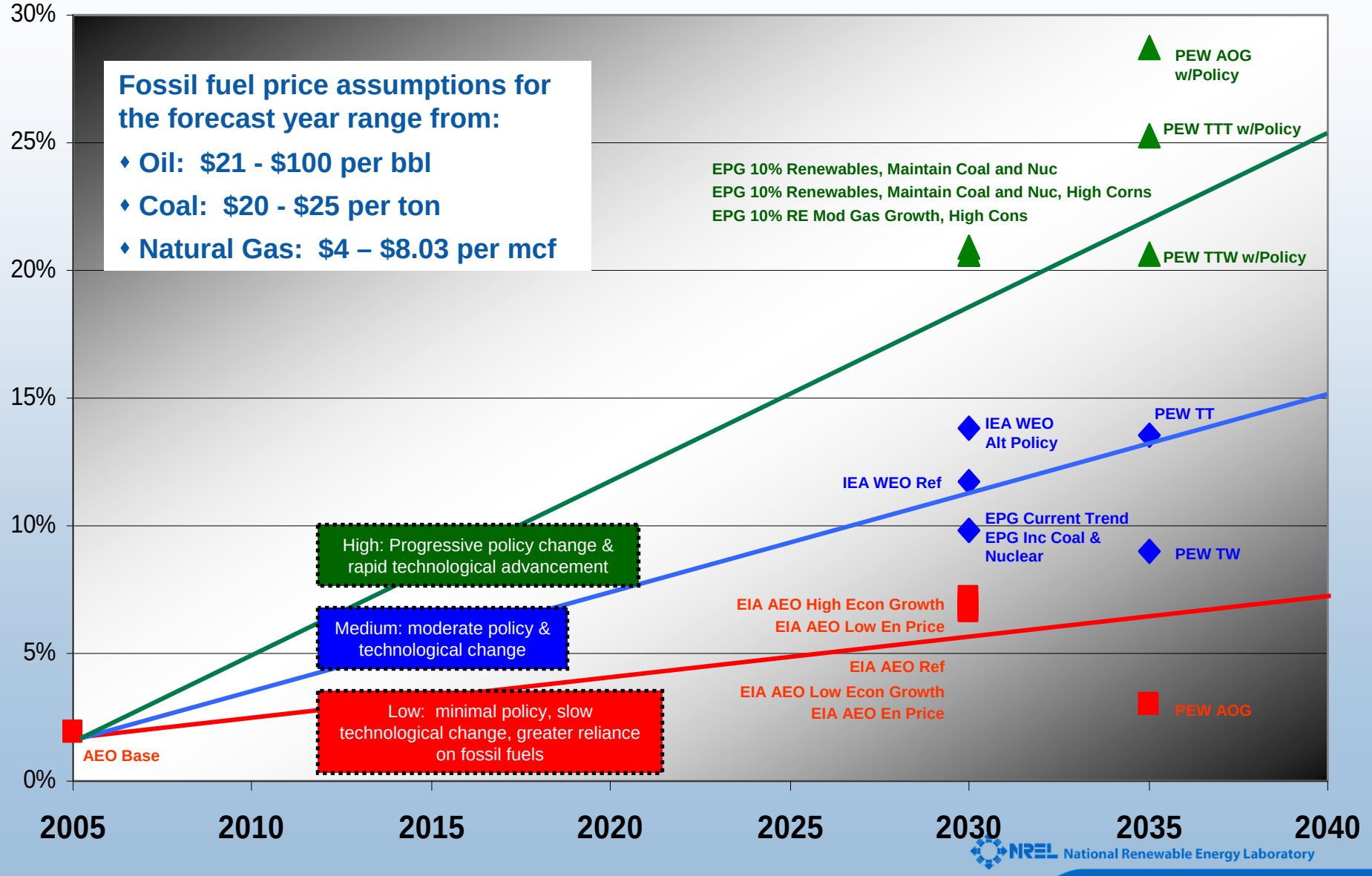
## Electricity Net Generation – 2006




* Source: EIA Annual Energy Review 2007

# U.S. Renewable Energy Contributions

## Percent of Total Electric Generating Capacity



# We Are Now Setting Aspirational National Goals
# Setting the Bar Higher

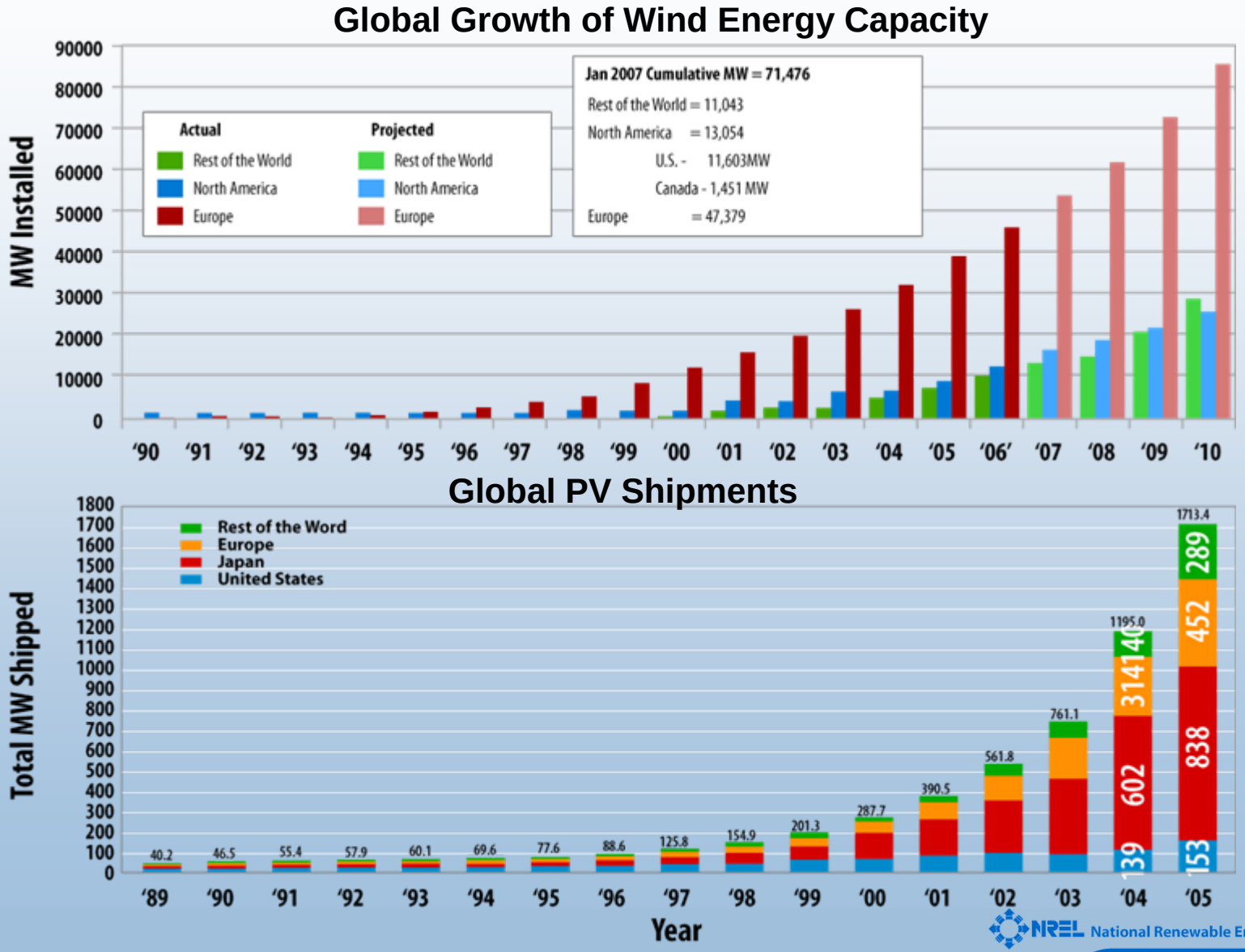
## U.S. national goals

- Wind: 20% of total provided energy by 2030
- Solar: Be market competitive by 2015 for PV and CSP
- Geothermal: <5¢/kWh, for typical hydrothermal sites and 5¢/kWh, for enhanced geothermal systems with mature technology

# Getting to “Significance” Involves…

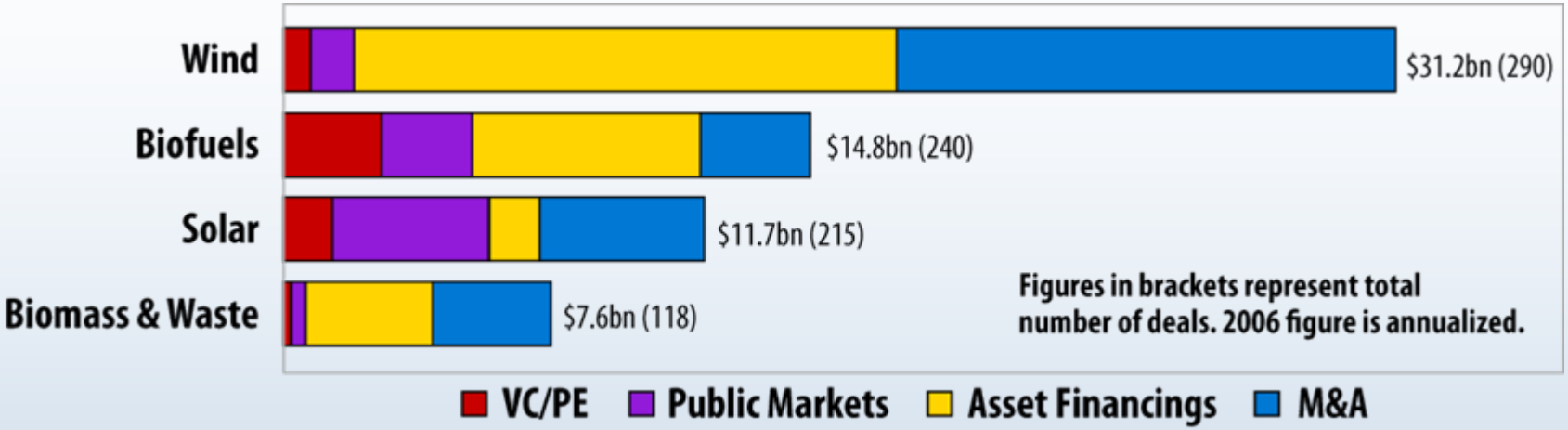

Source: NREL

# Global Markets are Growing Rapidly

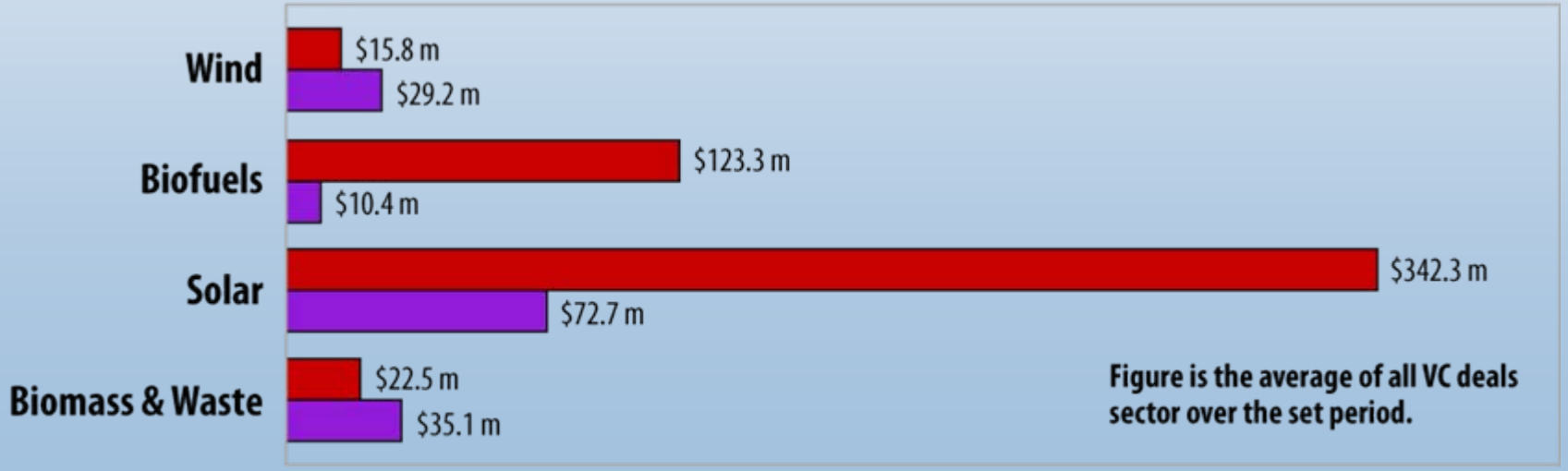


# Money Is Flowing Into the Sector

2006 Investment and M&A – By Sector and Asset Class

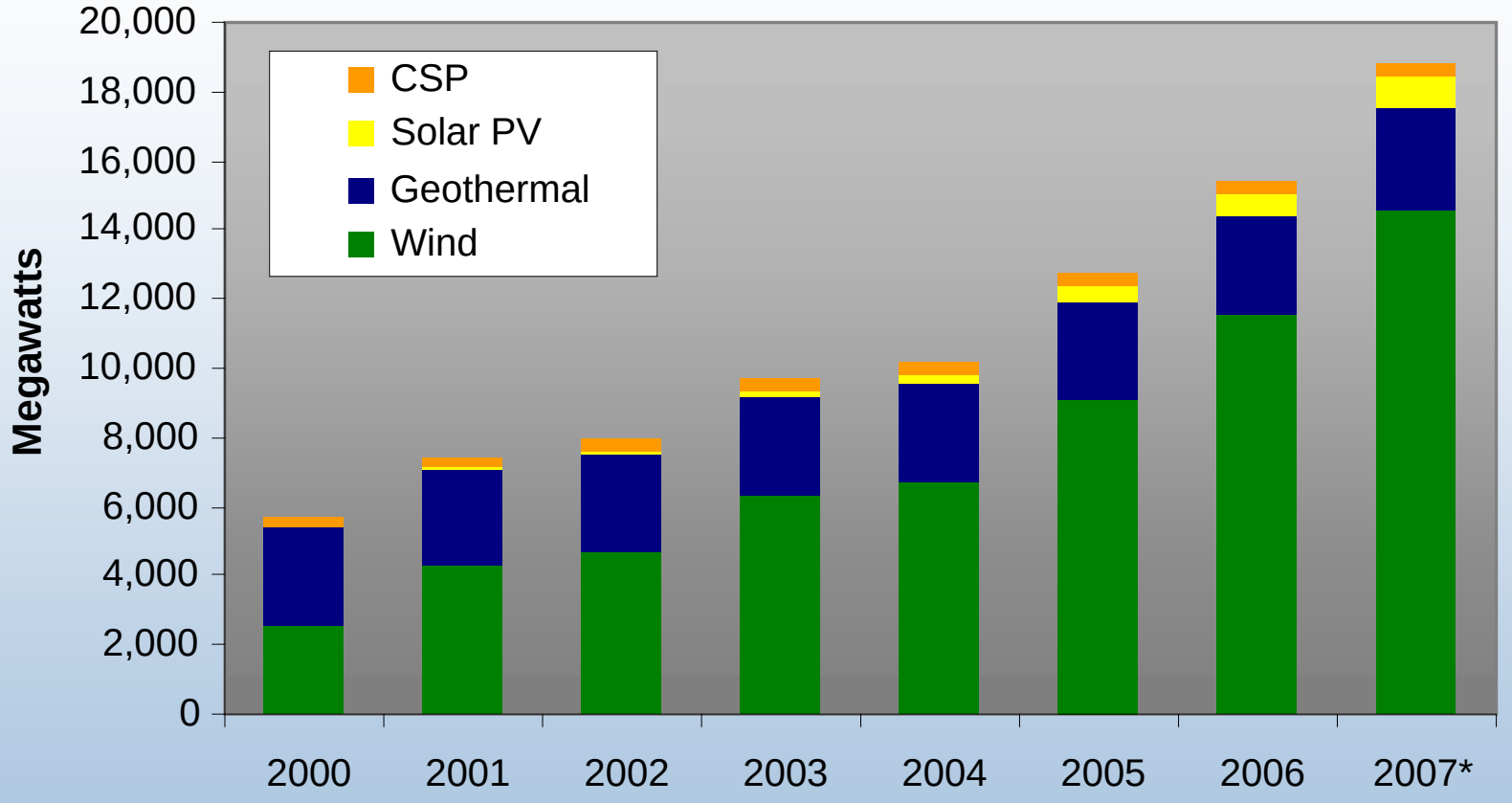



Annual VC Investment Volume – 2001-2004 Compared With 2005-2006




Source: New Energy Finance 2007

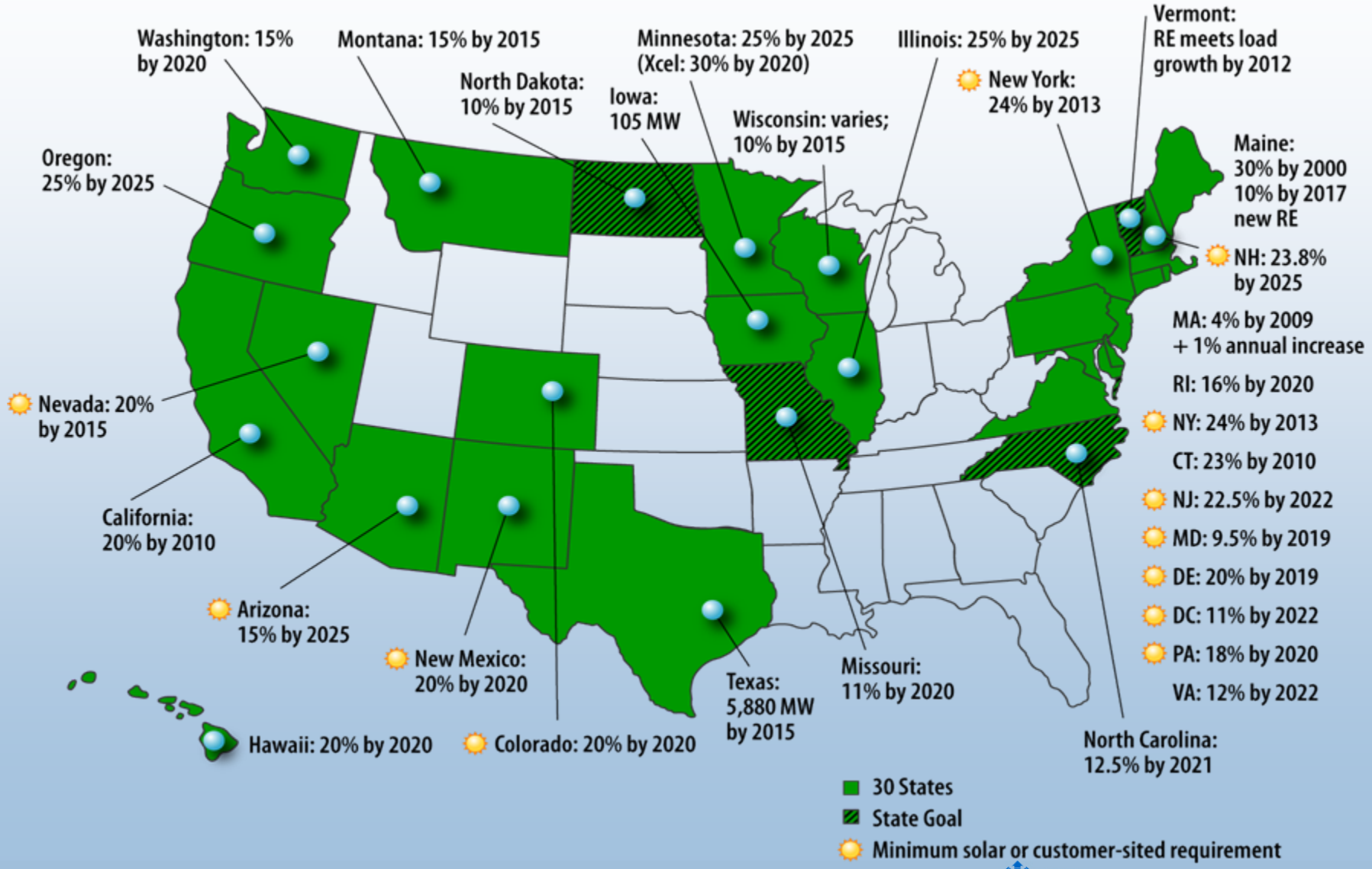
# U.S. New Renewable Energy Installed Capacity




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007(proj.) |
|---|---|---|---|---|---|---|---|---|
| **Annual growth (%)** | .2% | 30% | 6% | 22% | 5% | 25% | 21% | 22% |
| **Total capacity (MW)** | 5,730 | 7,470 | 7,940 | 9,690 | 10,160 | 12,740 | 15,420 | 18,841 |

Note: Excludes Hydropower & Biomass
*Projected. Does not include geothermal growth however there are about 3,000 MW in development
Source: EIA, NREL Analysis Office

# State Policy Framework
# Renewable Portfolio Standards

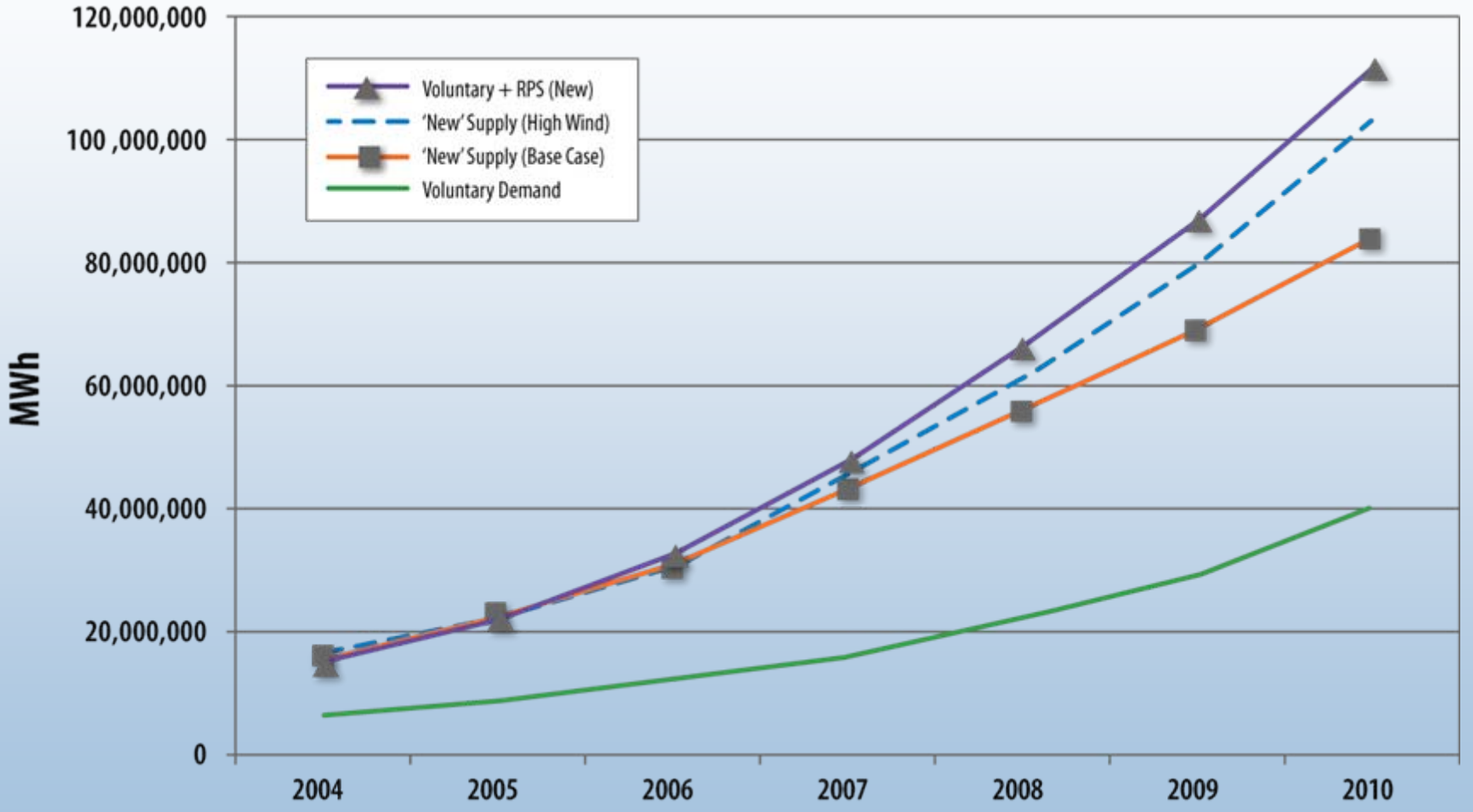



Source: DSIRE database, October 2007

# U.S. Voluntary Green Power Sales

| Millions of kWh | 2003 | 2004 | 2005 | 2006 | Change '06/05 |
|---|---|---|---|---|---|
| **Utility Green Pricing** | **1,300** | **1,800** | **2,500** | **3,400** | **39%** |
| Competitive Markets | 1,900 | 2,700 | 2,200 | 1,700 | -20% |
| REC Markets | 700 | 1,700 | 3,900 | 6,800 | 75% |
| Retail Total | 3,800 | 6,200 | 8,500 | 11,900 | 41% |

# Estimated and Projected Supply and Demand for Renewable Electricity




Green markets are increasing

Source: Blair Swezey, Jørn Aabakken, and Lori Bird, "A Preliminary Examination of the Supply and Demand Balance for Renewable Electricity", NREL Technical Report, NREL/TP-670-42266, October 2007. URL: http://www.nrel.gov/docs/fy08osti/42266.pdf

# NREL Energy Efficiency and Renewable Energy Technology Development Programs

NREL R&D Portfolio

## Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

## Renewable Resources

- Wind
- Solar
- Biomass
- Geothermal


## Energy Delivery and Storage

- Electricity Transmission and Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

**Foundational Science and Advanced Analytics**

# NREL Energy Efficiency and Renewable Energy Technology Development Programs

## Wind

### NREL Research Thrusts

- Improved turbine performance and reliability
- Distributed wind technology
- Drivetrain reliability
- Utility grid integration
- Exploring ocean kinetic and thermal energy

### Renewable Resources

- Wind
- Solar
- Geothermal

**Foundational Science and Advanced Analytics**

# NREL Energy Efficiency and Renewable Energy Technology Development Programs

## Renewable Resources

- Wind
- Solar
- Geothermal

## Solar
## NREL Research Thrusts

### PV

- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

### CSP

- Next generation solar collectors
- High performance storage

**Foundational Science and Advanced Analytics**

# NREL Energy Efficiency and Renewable Energy Technology Development Programs

## Renewable Resources

- Wind
- Solar
- Geothermal

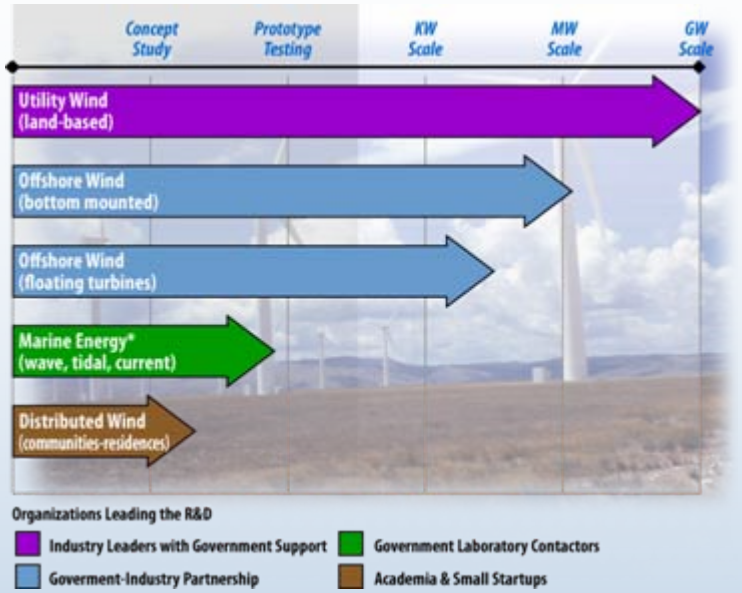
## Geothermal
## NREL Research Thrusts

- Analysis to define technology path to commercialization of Enhanced Geothermal Systems (EGS)
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

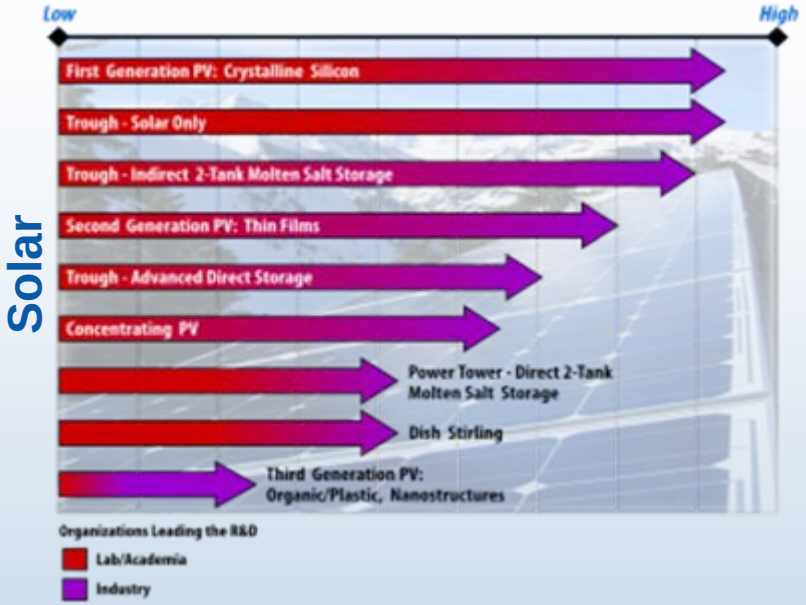
**Foundational Science and Advanced Analytics**

# Technology Options Are Evolving

## Wind

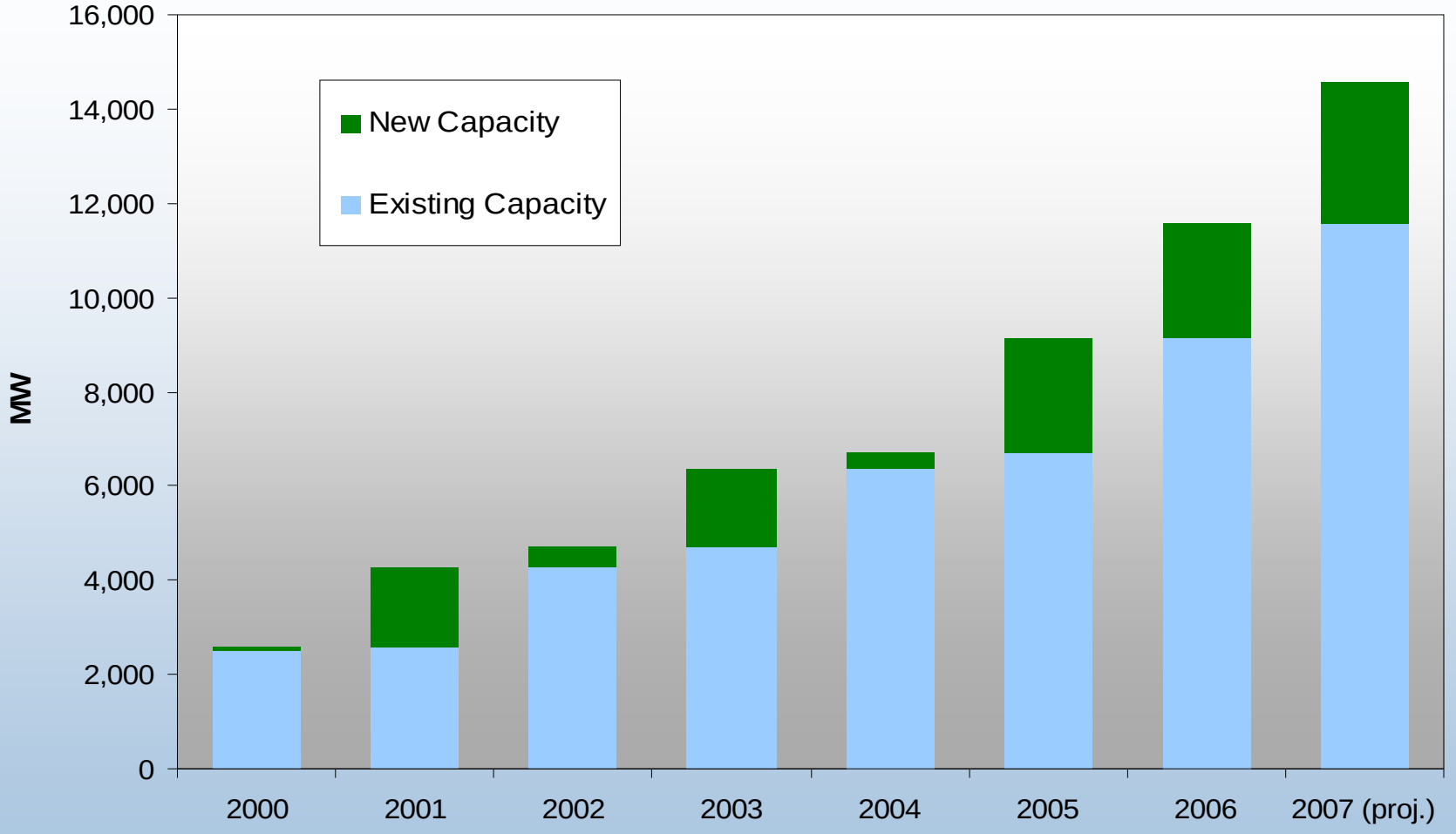



## Solar




## Geothermal

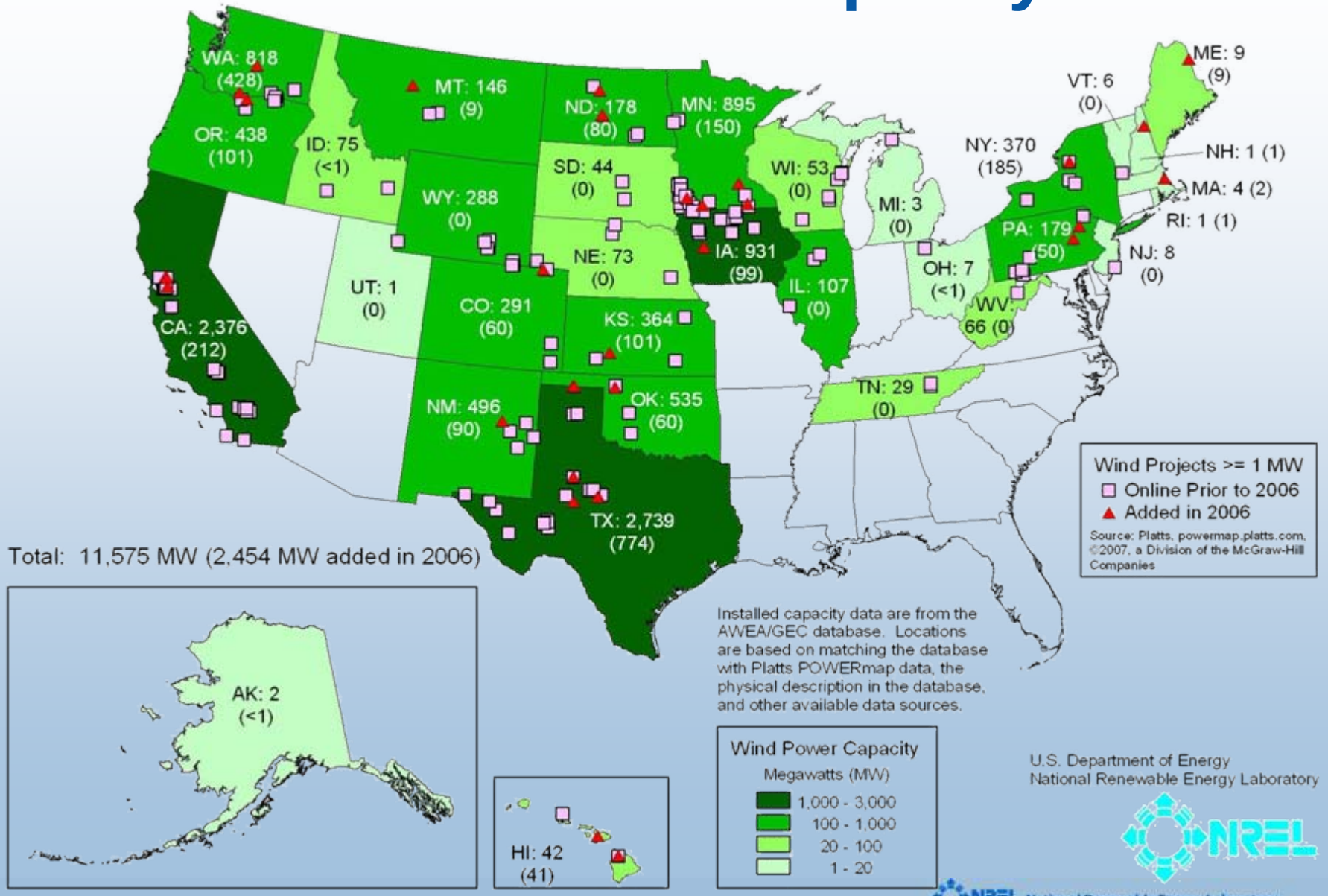
# U.S. Wind Capacity Growth




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007(proj.) |
|---|---|---|---|---|---|---|---|---|
| **Annual growth (%)** | 3% | 66% | 10% | 36% | 6% | 36% | 27% | 26% |
| **Total capacity (MW)** | 2,578 | 4,275 | 4,686 | 6,353 | 6,725 | 9,121 | 11,575 | 14,575 |

Source: AWEA; Ryan Wiser (LBL)

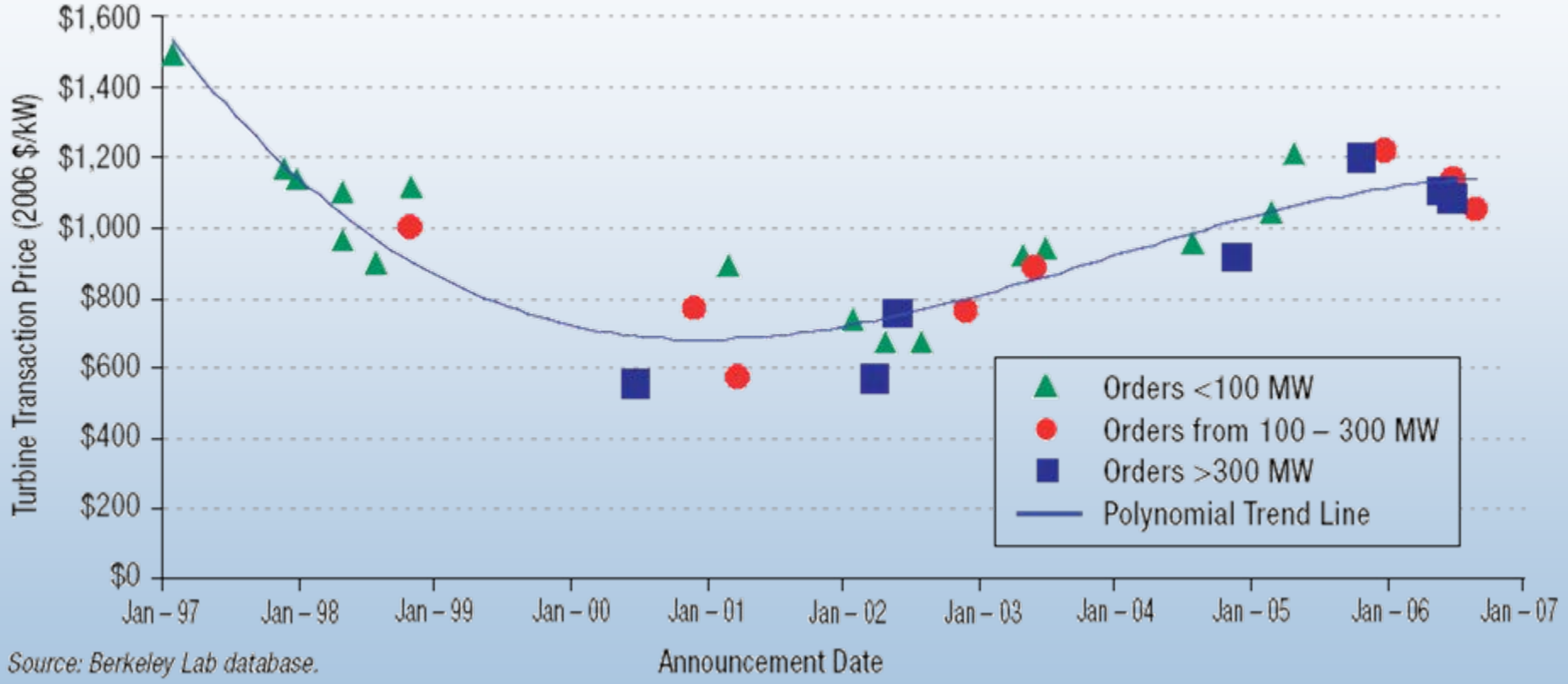
# Installed Wind Capacity



# Wind Energy Challenges: Deploying 300 GW of Wind by 2030

- Understanding and acceptance by financial sector, regulators, utilities and public
- Integrating wind onto the grid at a large scale
  - Transmission resources
  - Advanced forecasting and predictive capabilities
- Rising costs driven by inconsistent policies and increased competition
- Poor performance and reliability

# Project Cost Increases Are a Function of Turbine Prices




**Reported U.S. Wind-Turbine Transaction Prices Over Time**

# Integrating Wind Into Power Systems

New studies find integrating wind into power systems is manageable, but not costless

| Date | Study | Wind Capacity Penetration | Cost ($/MWh) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Regulation | Load Following | Unit Commitment | Gas Supply | TOTAL |
| 2003 | Xcel-UWIG | 3.5% | 0 | 0.41 | 1.44 | na | 1.85 |
| 2003 | We Energies | 4% | 1.12 | 0.09 | 0.69 | na | 1.90 |
| 2003 | We Energies | 29% | 1.02 | 0.15 | 1.75 | na | 2.92 |
| 2004 | Xcel-MNDOC | 15% | 0.23 | na | 4.37 | na | 4.60 |
| 2005 | PacifiCorp | 20% | 0 | 1.6 | 3 | na | 4.60 |
| 2006 | CA RPS (multi-year) | 4% | 0.45* | trace | na | na | 0.45 |
| 2006 | Xcel-PSCo | 10% | 0.2 | na | 2.26 | 1.26 | 3.72 |
| 2006 | Xcel-PSCo | 15% | 0.2 | na | 3.32 | 1.45 | 4.97 |
| 2006 | MN-MISO 20% | 31% | na | na | na | na | 4.41** |

* *3-year average* ** *highest over 3-year evaluation period*

**Key Results from Major Wind Integration Studies Completed 2003-2006**

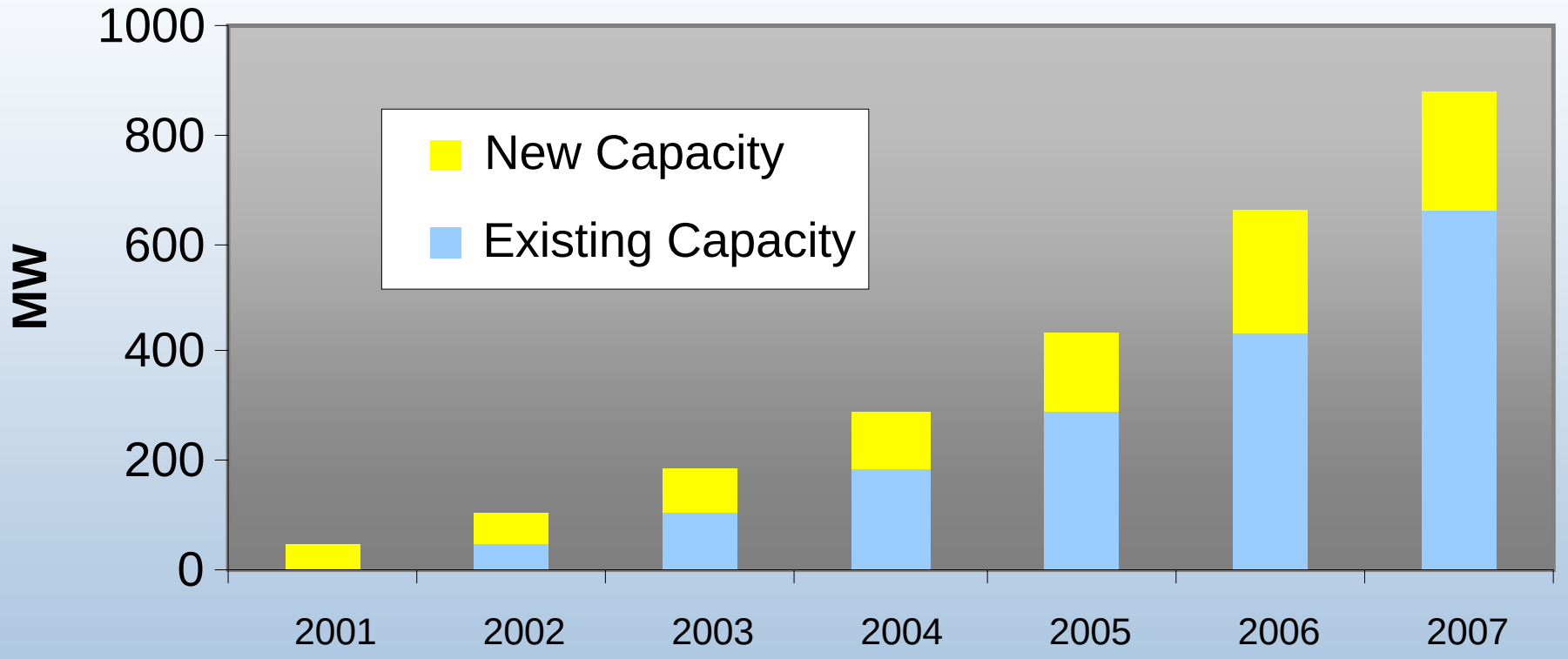
# Some Additional Reserves May Need to be Committed

| Reserve Category | Base | | 15% Wind | | 20% Wind | | 25% Wind | |
|---|---|---|---|---|---|---|---|---|
| | MW | % | MW | % | MW | % | MW | % |
| **Regulating** | 137 | 0.65% | 149 | 0.71% | 153 | 0.73% | 157 | 0.75% |
| **Spinning** | 330 | 1.57% | 330 | 1.57% | 330 | 1.57% | 330 | 1.57% |
| **Non-Spin** | 330 | 1.57% | 330 | 1.57% | 330 | 1.57% | 330 | 1.57% |
| **Load Following** | 100 | 0.48% | 110 | 0.52% | 114 | 0.54% | 124 | 0.59% |
| **Operating Reserve Margin** | 152 | 0.73% | 310 | 1.48% | 408 | 1.94% | 538 | 2.56% |
| Total Operating Reserves | **1049** | **5.00%** | **1229** | **5.86%** | **1335** | **6.36%** | **1479** | **7.05%** |

Source MN DOC

Estimated Operating Reserve Requirement for MN BAs – 2020 Load

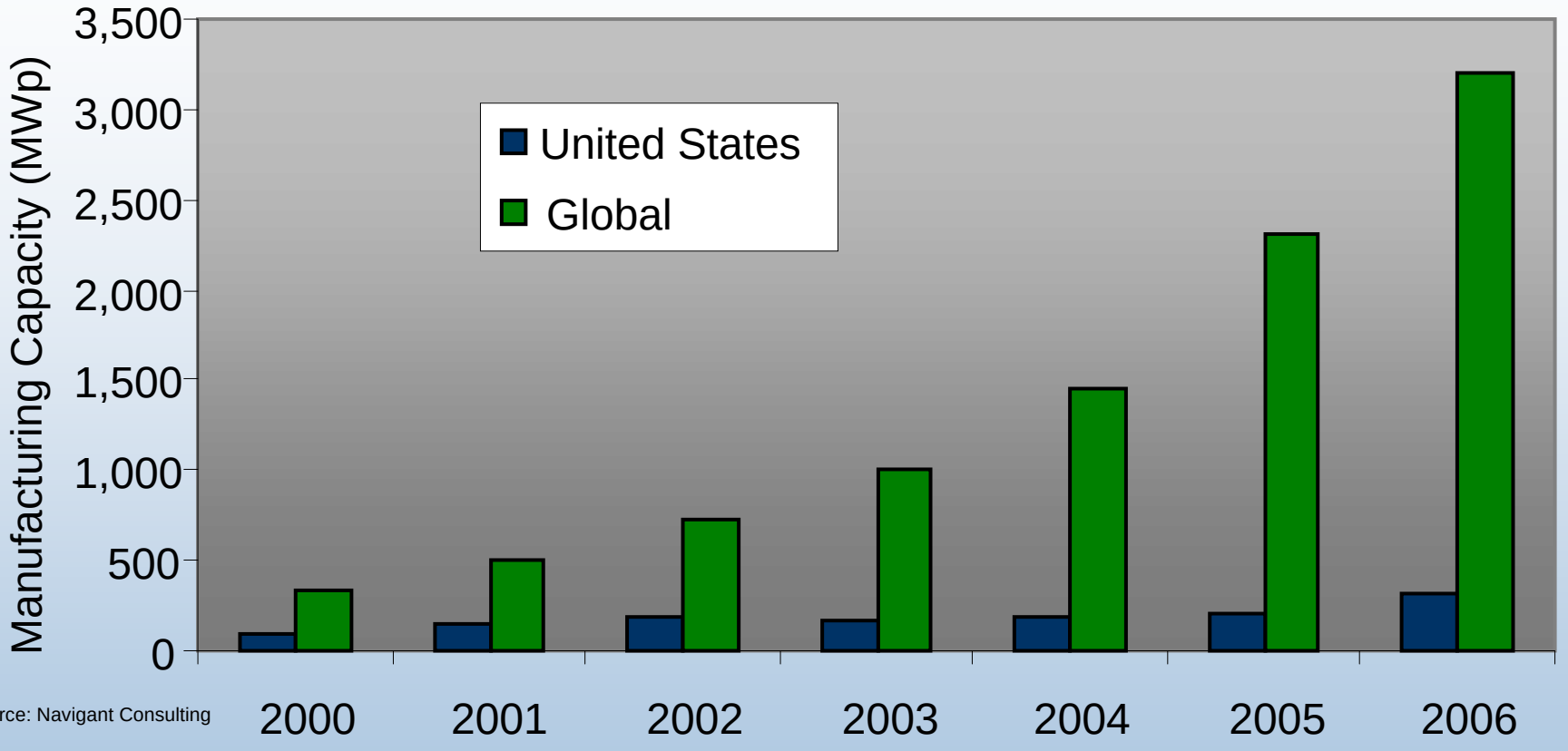
# U.S. Solar Photovoltaic Capacity Growth




| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007* |
|---|---|---|---|---|---|---|---|
| **Annual growth (%)** | n/a | 134% | 72% | 57% | 48% | 52% | 34% |
| **Total capacity (MW)** | 46 | 108 | 186 | 291 | 432 | 658 | 883 |

Source: Navigant Consulting/Piper Jaffray

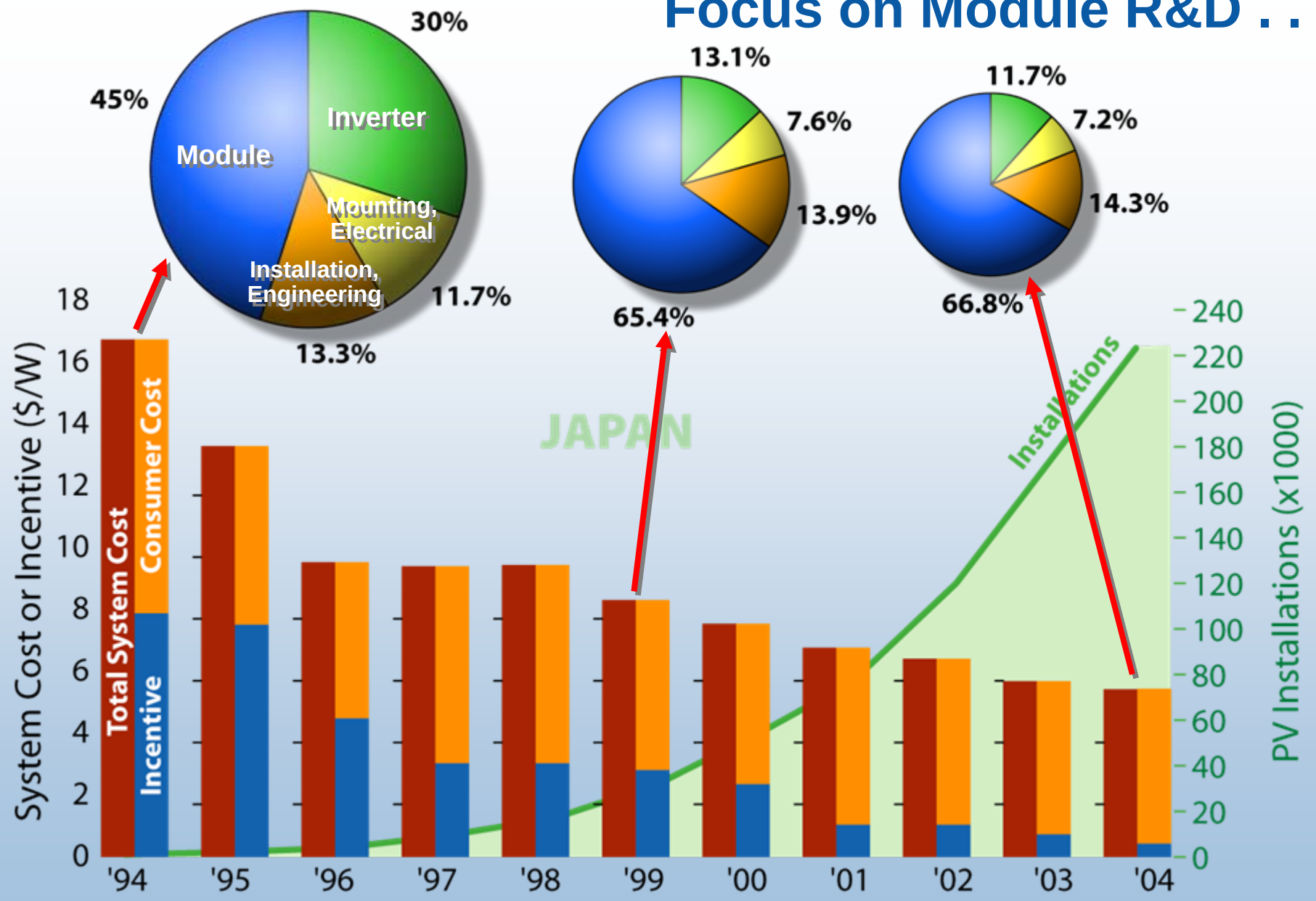
# Solar Manufacturing Capacity




Source: Navigant Consulting

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|
| **Total Global Manufacturing Capacity (MWp)** | 225 | 328 | 504 | 728 | 1,002 | 1,460 | 2,303 |
| **Annual Global Growth** | 28% | 54% | 45% | 38% | 46% | 58% | 39% |
| **Total U.S. Manufacturing Capacity (MWp)** | 90 | 143 | 179 | 170 | 186 | 212 | 314 |
| **Annual U.S. Growth** | 14% | 58% | 26% | -5% | 9% | 14% | 48% |

# Focus on Module R&D . . .

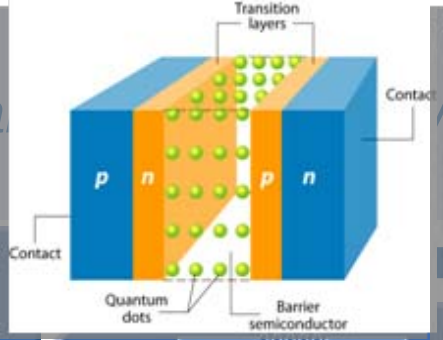


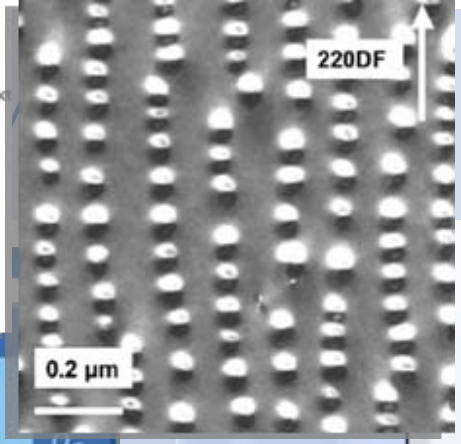
# R&D

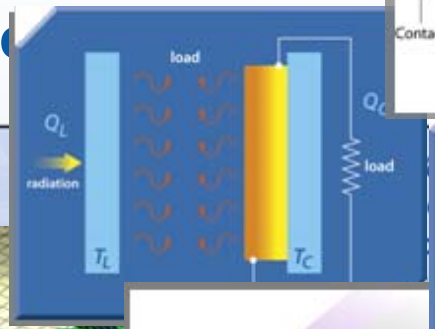
*Ensures technology ownership, ena*

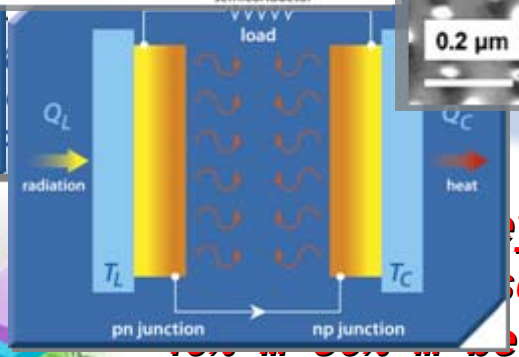
DOE is the STEWARD

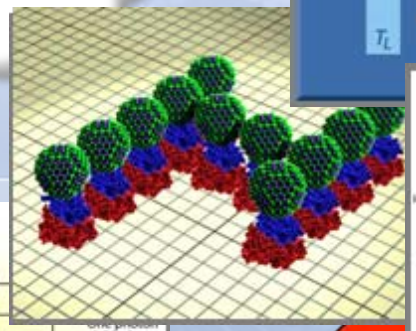
## PV Module Pr

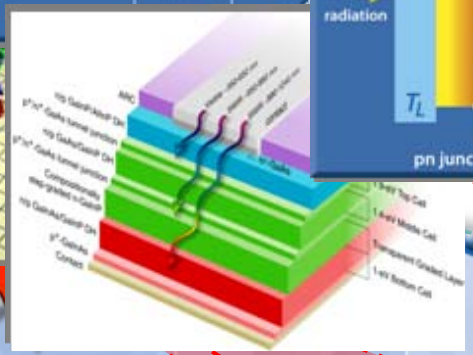


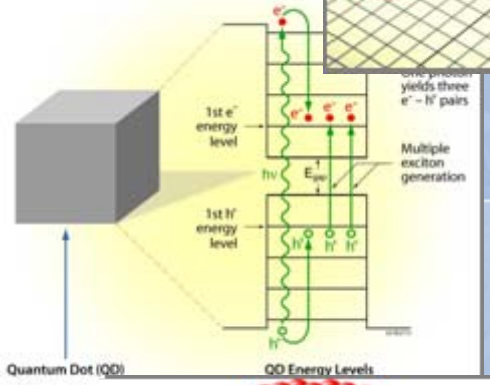



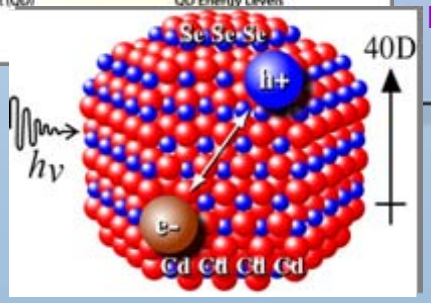








(2004$/Wp)

100

10.0

*...eyond the ...ser Limit ...eyond?)*

90%

80%

80%

70%

60%

***Disruptive II***

***3rd Gen and beyond***

**Quantum dots**

**Nanotechnology**

**Multi-multi-junctions**

**Thermophotonics, voltaics**

**Intermediate band . . .**

SEIA 2020

EPIA 2020

EPIA 2030

10 100 1,000 10,000 100,000 1,000,000

Cumulative Production (MWp)

# DOE National Lab module research balances various materials thru joint industry R&D and long-term research

## 4% Organic PV

Customizing organic molecules for optimal cell efficiency in materials that can be processed without expensive vacuum chambers

## 1% Dye Sensitized Cells

Advancing the efficiency and stability of inexpensive dye-based solar cells with novel nanostructures

## 22% Wafer Silicon

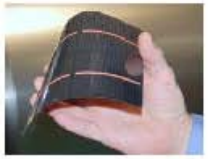
Combining thin amorphous and wafer silicon to make high efficiency cells with smaller total amounts of silicon

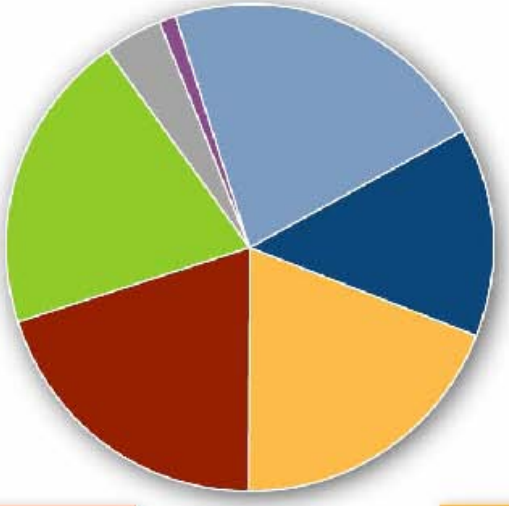
Developing new ink-jet printing methods for silicon electrical contacts

## 20% Thin Films (CIGS)

Supporting the novel manufacture of CIGS cells from ink-based precursors

Transferring discovery that highest performance material has nanostructured patterns into a fast and uniform manufacturing process





## 14% Concentrator PV

Devising strategies for making quicker, easier, less precise cells but maintaining record performance

Achieving record efficiencies (33.8%) even without concentration

## 20% Thin Films (CdTe)

Produced thinner films with same cell performance

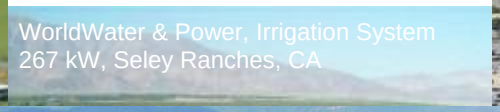
Discovered a more durable way to make electrical contacts

## 19% Thin Films (Silicon)

Developing methods of making thin silicon film solar cells on inexpensive glass and at low processing temperatures

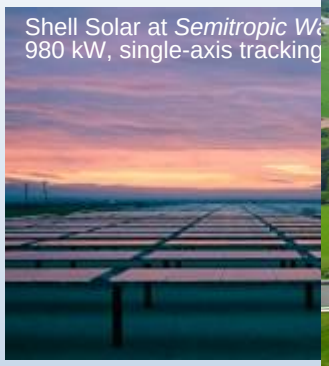
# Moving Toward Our Destination


Ridge
Vineyards
PV Rooftop
65 kW, CA


WorldWater & Power, Irrigation System
267 kW, Seley Ranches, CA


RWE Schott Stillwell Avenue Subway Station, PV Canopy Roof, 250,000 kWh/yr, Brooklyn, NY


Powerlight, Bavarian community
6.750 MW, single-axis tracking
Mühlhausen, Germany

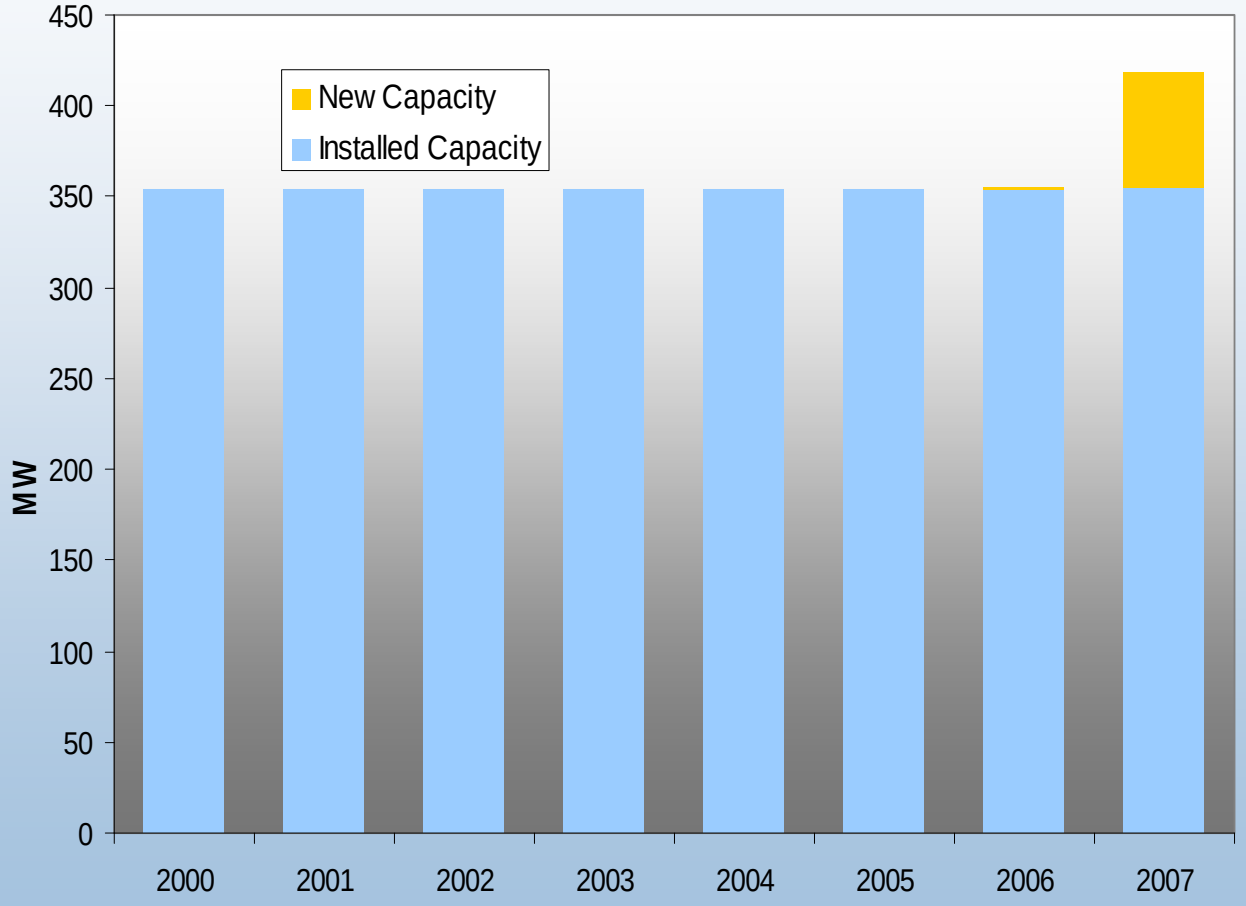

Shell Solar at *Semitropic Wa*
980 kW, single-axis tracking


er & Geothermal Energy Co.
stewater Plant, 622 kW,
CA


PowerLight PowerGuard
536 kW, Toyota Motor C


op system,

# U.S. Concentrating Solar Power Capacity Growth




| | Annual growth (%) | Total capacity (MW) |
|---|---|---|
| **2000** | 0% | 354 |
| **2001** | 0% | 354 |
| **2002** | 0% | 354 |
| **2003** | 0% | 354 |
| **2004** | 0% | 354 |
| **2005** | 0% | 354 |
| **2006** | 0.3% | 355 |
| **2007** | 18% | 419 |

# CSP Industry is Still Taking Shape

Thermal Storage R&D

- Enabling solar generated power to be delivered to grid any time needed by utilities

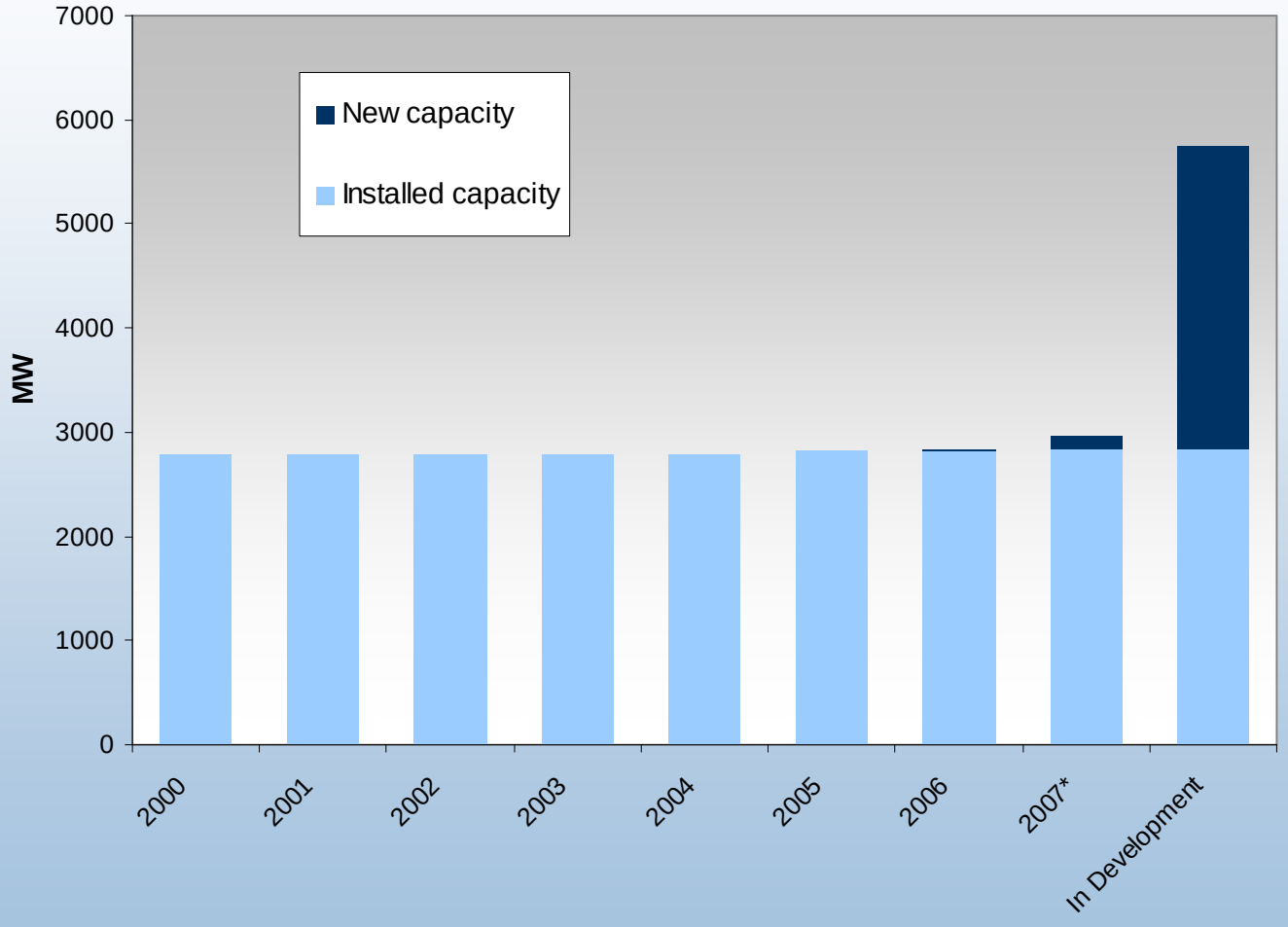
Transition to High Volume Manufacturing

- Reduce costs and increase supply base for critical components

Advanced Concepts

- Explore new technologies that could significantly reduce system and/or component cost

# U.S. Geothermal Capacity Growth

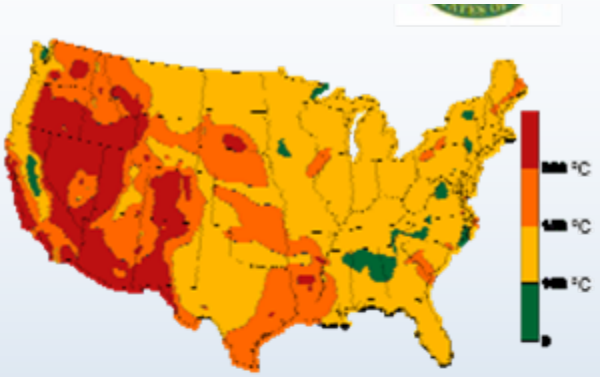



| | Annual growth (%) | Total capacity (MW) |
|---|---|---|
| **2000** | 0% | 2,793 |
| **2001** | 0% | 2,793 |
| **2002** | 0% | 2,793 |
| **2003** | 0% | 2,793 |
| **2004** | 0% | 2,793 |
| **2005** | 1.3% | 2,828 |
| **2006** | 0.1% | 2,831 |
| **2007 (proj)** | 5% | 2,964 |

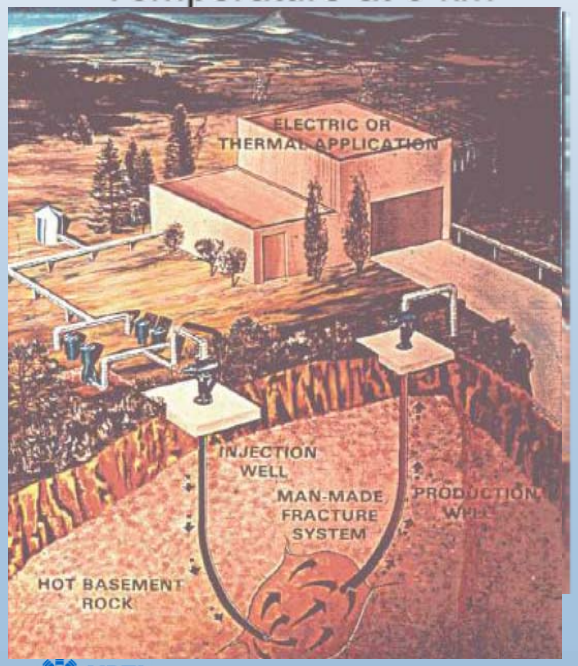
*Projected
Sources: GEA, WGA Task Force, IEA

# Enhanced Geothermal Systems (EGS) for Electricity Generation

- **Problem Technology Addresses:** Base load power generation with few or no emissions.
  - **Size of Problem:** Significant shortfall in projected U.S. power generation. Coal may not be able to meet the deficit.
- **Description:** EGS involves engineering a hydrothermal reservoir via fracturing and injection of water to extract heat from the earth.
- **Impact:**
  - Up to 10% (100 GWe) of the current power generation capacity can be from EGS, with potential to install much more.
  - There are essentially no carbon or other gaseous emissions and the geothermal resource is sustainable.
  - The resource exists across the nation.
- **IP Position:** Public domain, with the opportunity for many inventions.
- **Status:**
  - The EGS concept has been shown to be technically feasible at sites in several countries, including the United States.
  - The challenge is to improve EGS technology to ensure economic viability at commercial sites.
  - Field tests are required, starting with improving existing hydrothermal reservoirs, proceeding to expanding existing hydrothermal reservoirs, and ultimately creating reservoirs in challenging conditions.
  - For full-scale EGS development, about $50M to $100M/site.
  - Although the current working fluid is water, there exists the potential for other working fluids such as supercritical carbon dioxide, with attendant sequestration of the carbon. The carbon dioxide working fluid concept is patented and available for licensing, but field testing is required.



Temperature at 6 km




Source: DOE, August 2007

# Integrating Transportation and Electricity: Plug-In Hybrid Electric Vehicles (PHEV)

**Status**

- PHEV-only conversion vehicles available
- OEMS building prototypes
- NREL PHEV Test Bed

**NREL Research Thrusts**

- Energy storage
- Advanced power electronics
- Vehicle ancillary loads reduction
- Vehicle thermal management
- Utility interconnection
- Vehicle-to-grid

# Tying It All Together

Technologies

Reducing Risk

Mobilizing Capital

Policies

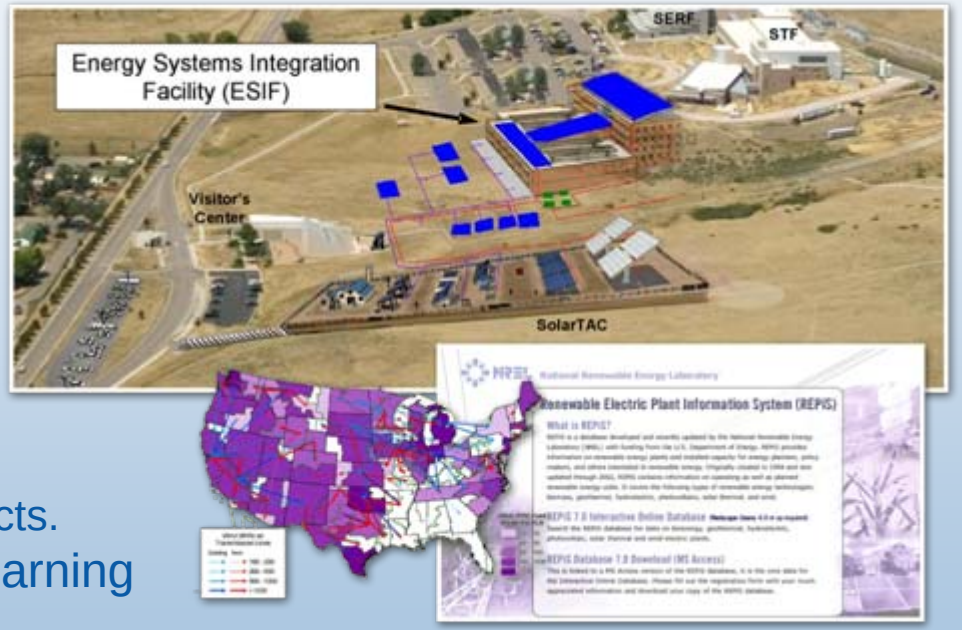
Markets

*Closing the gap between technology readiness and policy drivers…*

# Advanced Analytics Underpin Technology

- Key Areas:
  - Geospatial analytics
  - Decision making under uncertainty: Risk Mitigation and Planning
  - Temporal Impacts of Climate Change

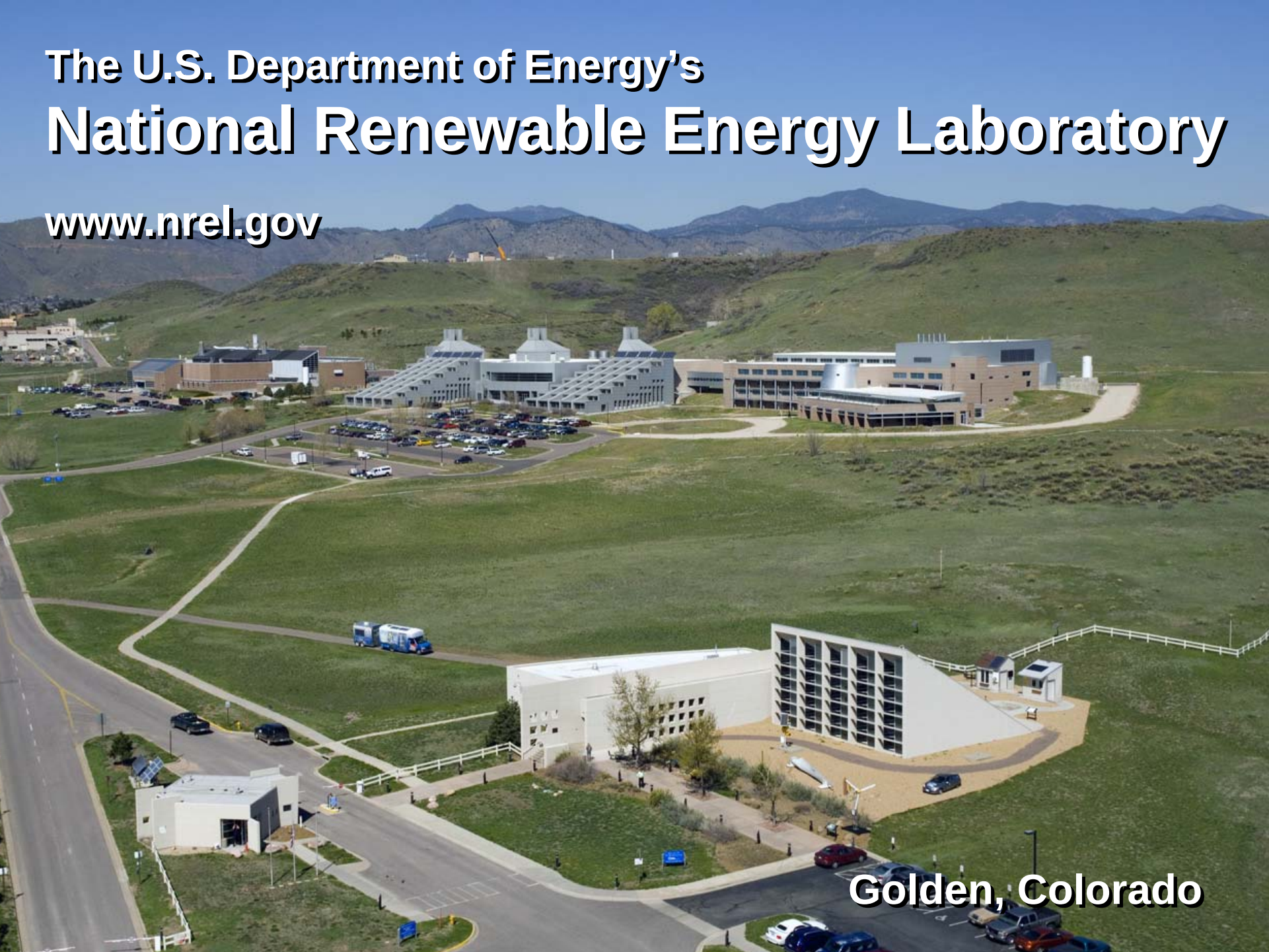
- NREL Thrusts
  - Geospatial characteristics
    - Resource
    - Transmission
    - Emissions
  - Cross Sector opportunities
    - PHEVs
    - Distributed generation plants
    - Cross Sector economics impacts.
  - Technology advancements—learning



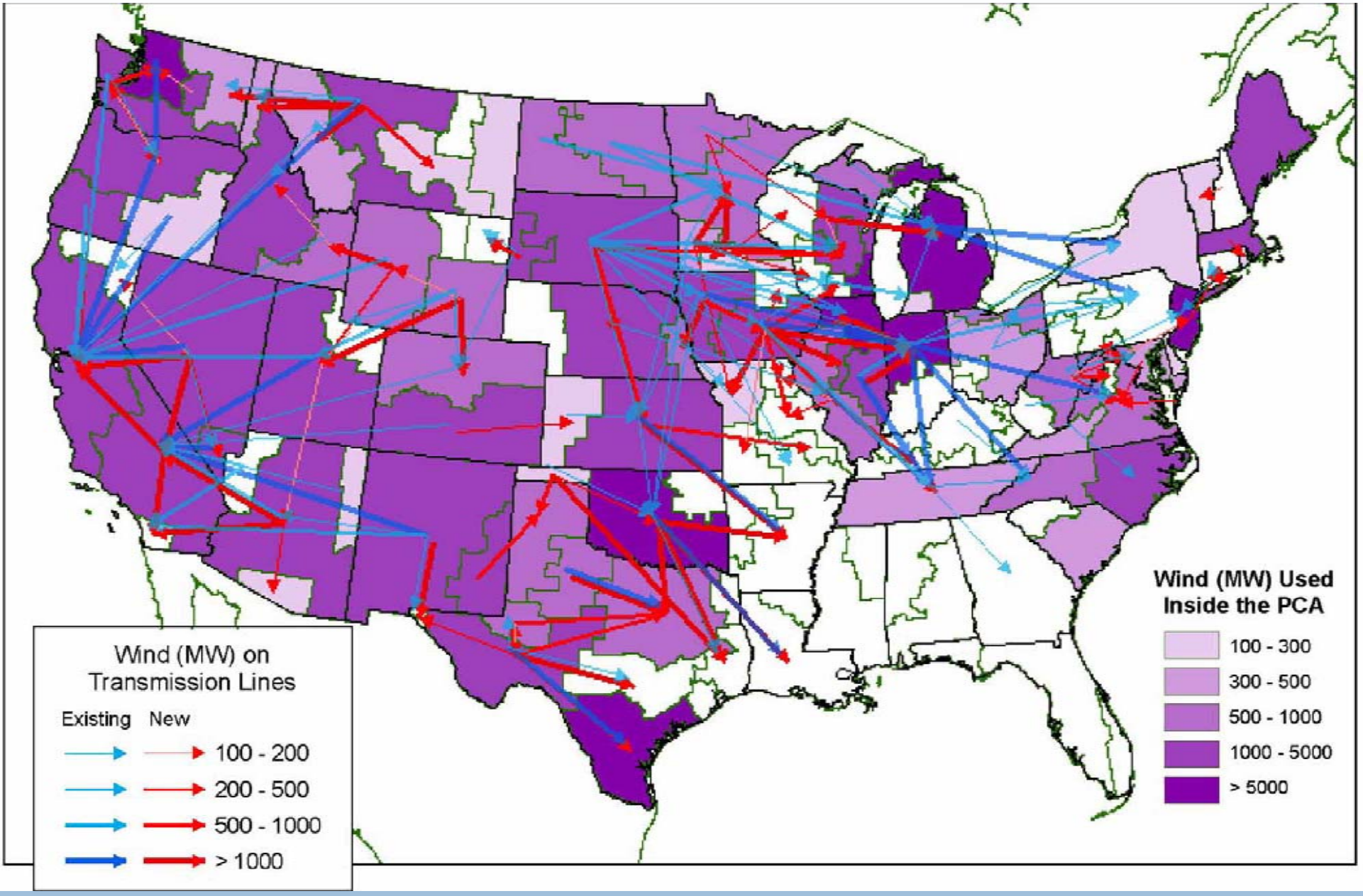

- Agent-based modeling to better capture market dynamics
- Advanced valuation methodologies
  - Real Options

# Achieving the Right Balance:
## Technology Investment Pathways

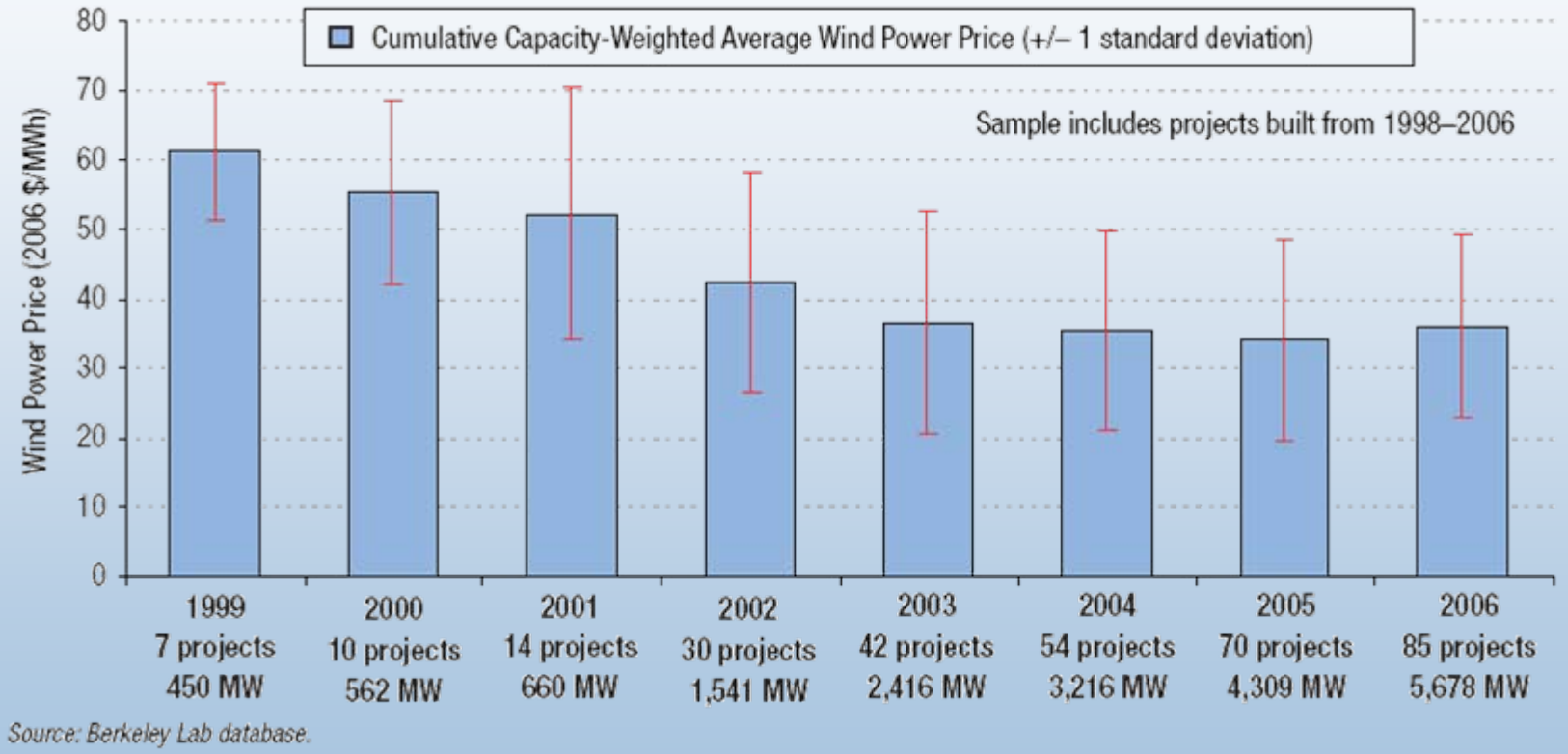

Source: NREL 2007


The U.S. Department of Energy's
National Renewable Energy Laboratory
www.nrel.gov
Golden, Colorado

# WinDS 2030 20% RPS for NWCC: Transmission and Consumption



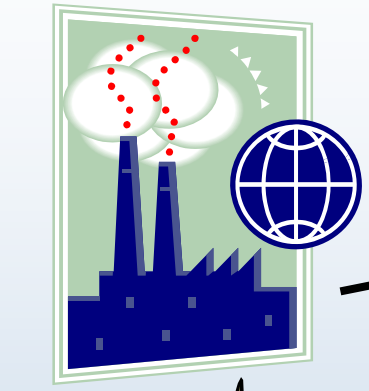
# Wind Power Prices – Up in 2006

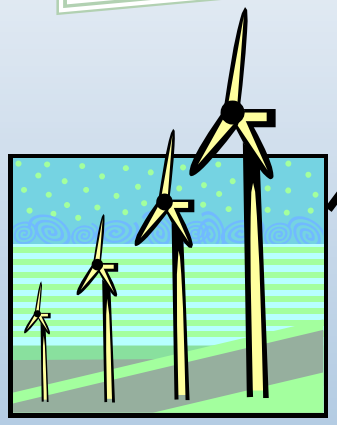



*Source: Berkeley Lab database.*

**Cumulative Capacity-Weighted Average Wind Power Price Over Time**

# Plug-in Hybrid Electric Vehicle Modeling





"The Grid"

Loads

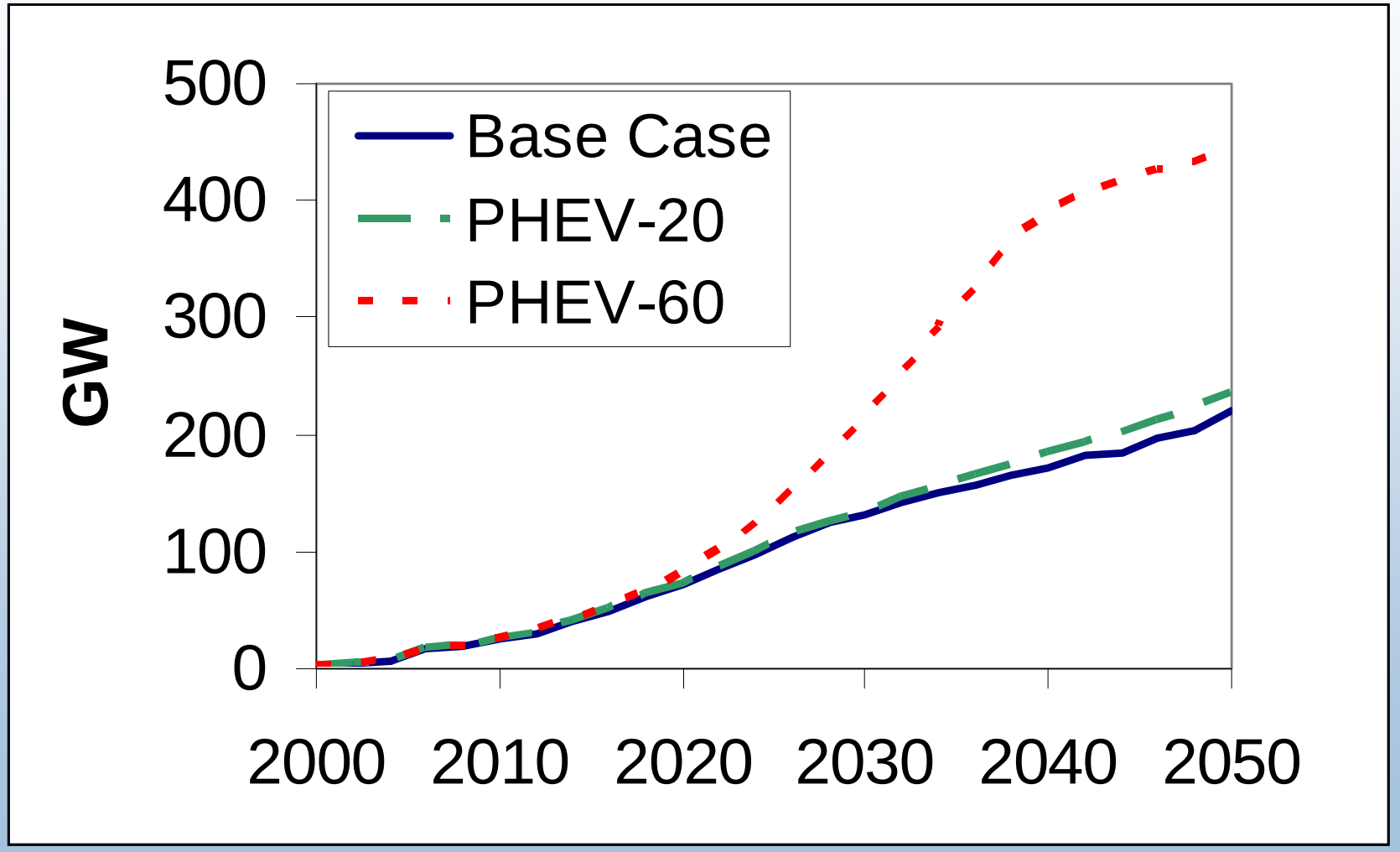
Reserve Margins

Ancillary Services

Off peak

*Reserves as needed*

# PHEVs* Can Increase Wind Penetration




* Assumes 50% PHEV-V2G penetration by 2050